How to reconstruct vertical velocities?

Summary of results obtained by several groups:

- A. Pietri, F. D'ovidio and X. Capet (LOCEAN)
- B. Qiu (Hawaii)
- A. Ponte, P. Klein and P. Rivière (IFREMER)
- G. Lapeyre (LMD) and S. Berti (LML)

- Basically, two methods for reconstructing w:
  - ”Full method”: Solve an omega-equation
    - Deduced from primitive equations
    - Involves ***3D*** quantities: density and velocity field
  - ”Simplified method”: Solve a SQG equation
    - Strong assumption of SQG dynamics
    - Only involves ***surface*** quantities (SSH and/or density)
- *The first method will give better results but we need* (u, v, ρ) *at every depth!*

1st method: Vertical velocity from omega equation

$$\nabla_H \cdot (N^2 \nabla_H w) + f_0^2 \frac{\partial^2 w}{\partial z^2} = -2\nabla_H \cdot \mathbf{Q} + \underbrace{\text{term 1}}_{ageostrophy} + \underbrace{\text{term 2}}_{surface fluxes}$$

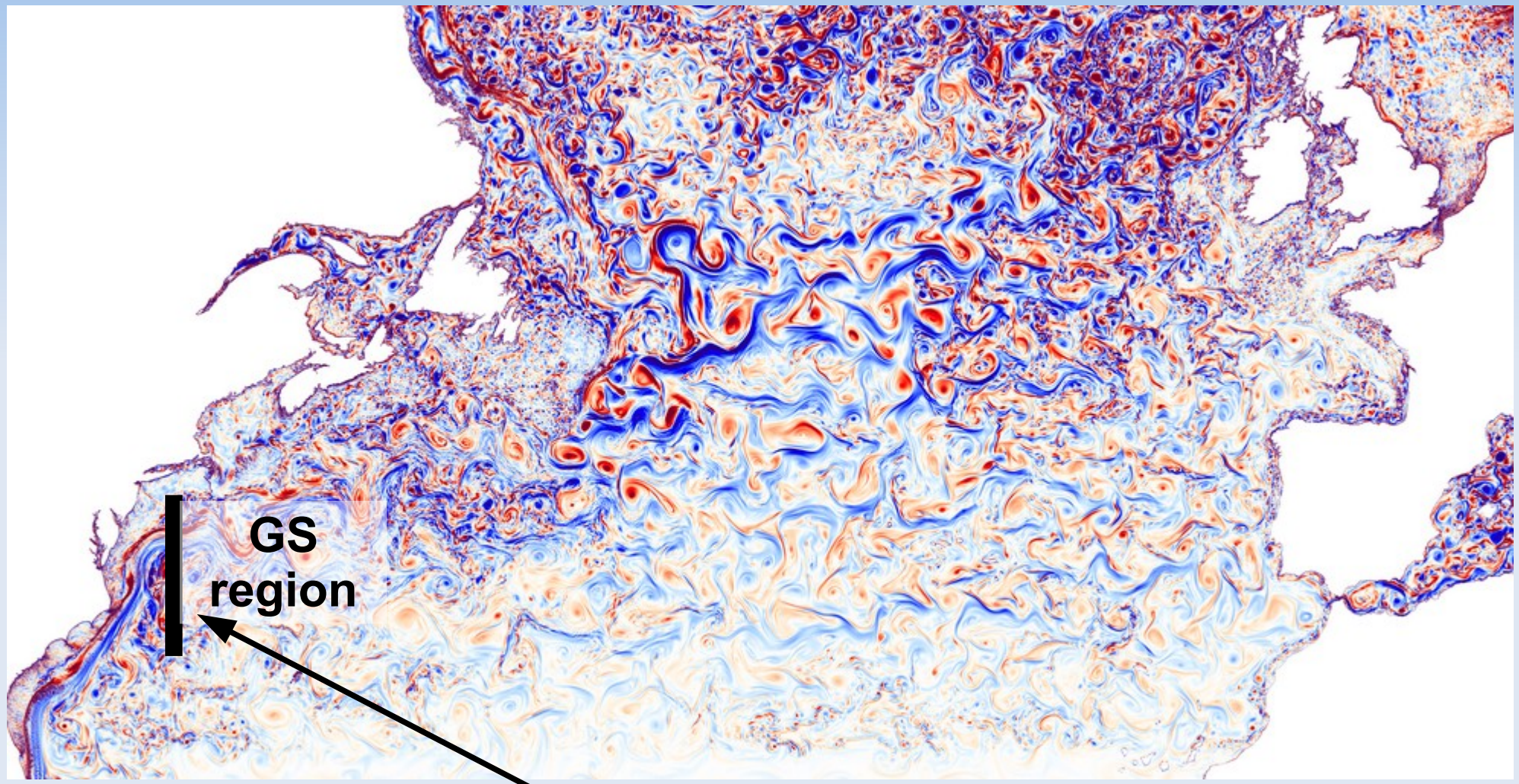
$$\mathbf{Q}(x, y, z) = \frac{2g}{\rho_0} \left[\nabla_H \mathbf{u}_H\right] \nabla_H \rho$$

➡ Inversion of a 3D elliptic equation. Needs

- 3D density field
- SSH for computation of horizontal velocity
- Surface fluxes (wind stress, buoyancy flux, vertical mixing)

- QG approximation with term 1 = term 2 = 0

North Atlantic simulation (1/60deg) (LGGE team, Grenoble)



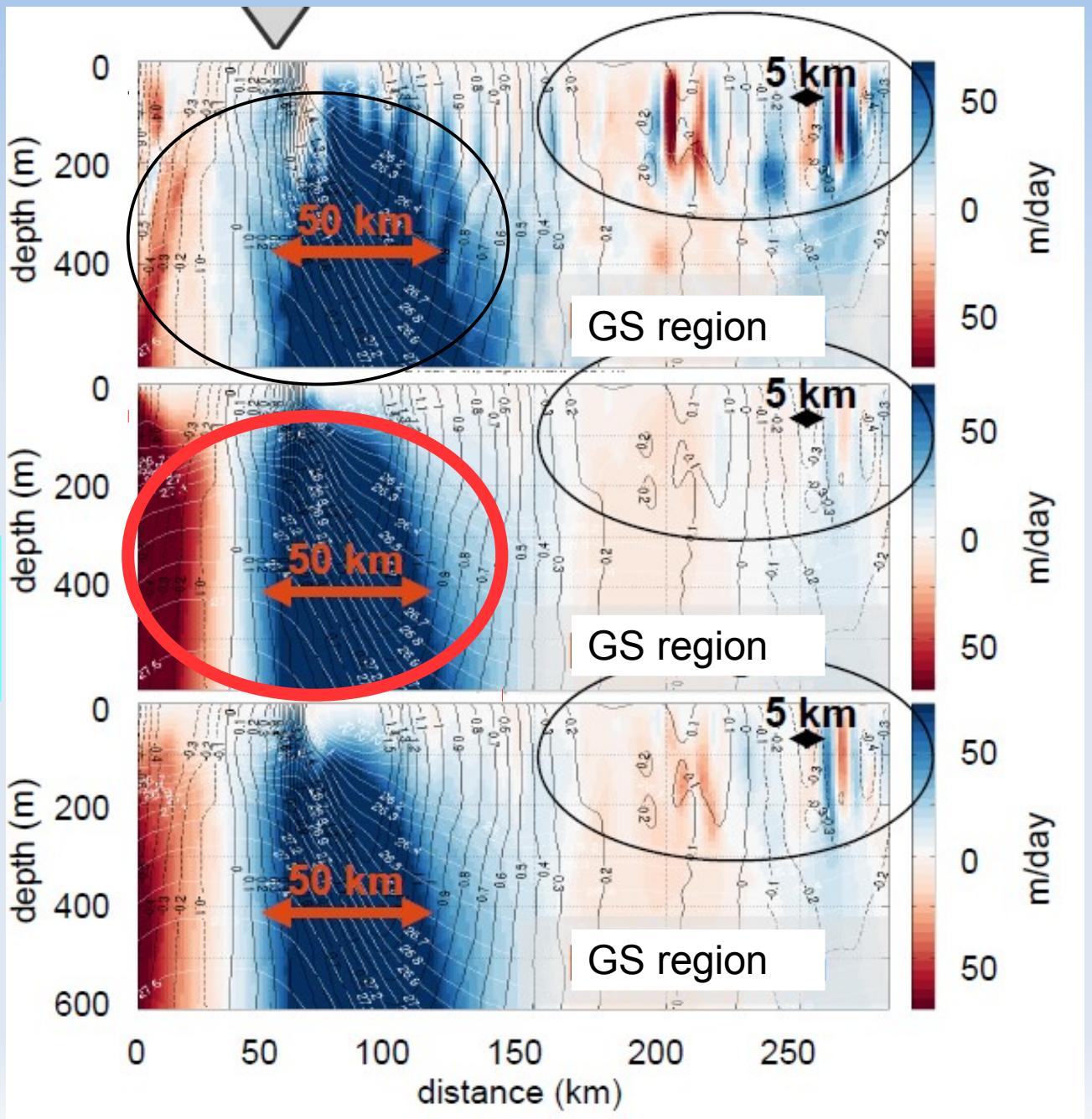
Vertical cross section in order to look at vertical velocities reconstruction

Vertical velocity reconstruction in GS region (Pietri, Capet and D'ovidio)

W from model

W from Q vector with QG terms only

Reconstruction of w at mesoscales (50km) and at depth

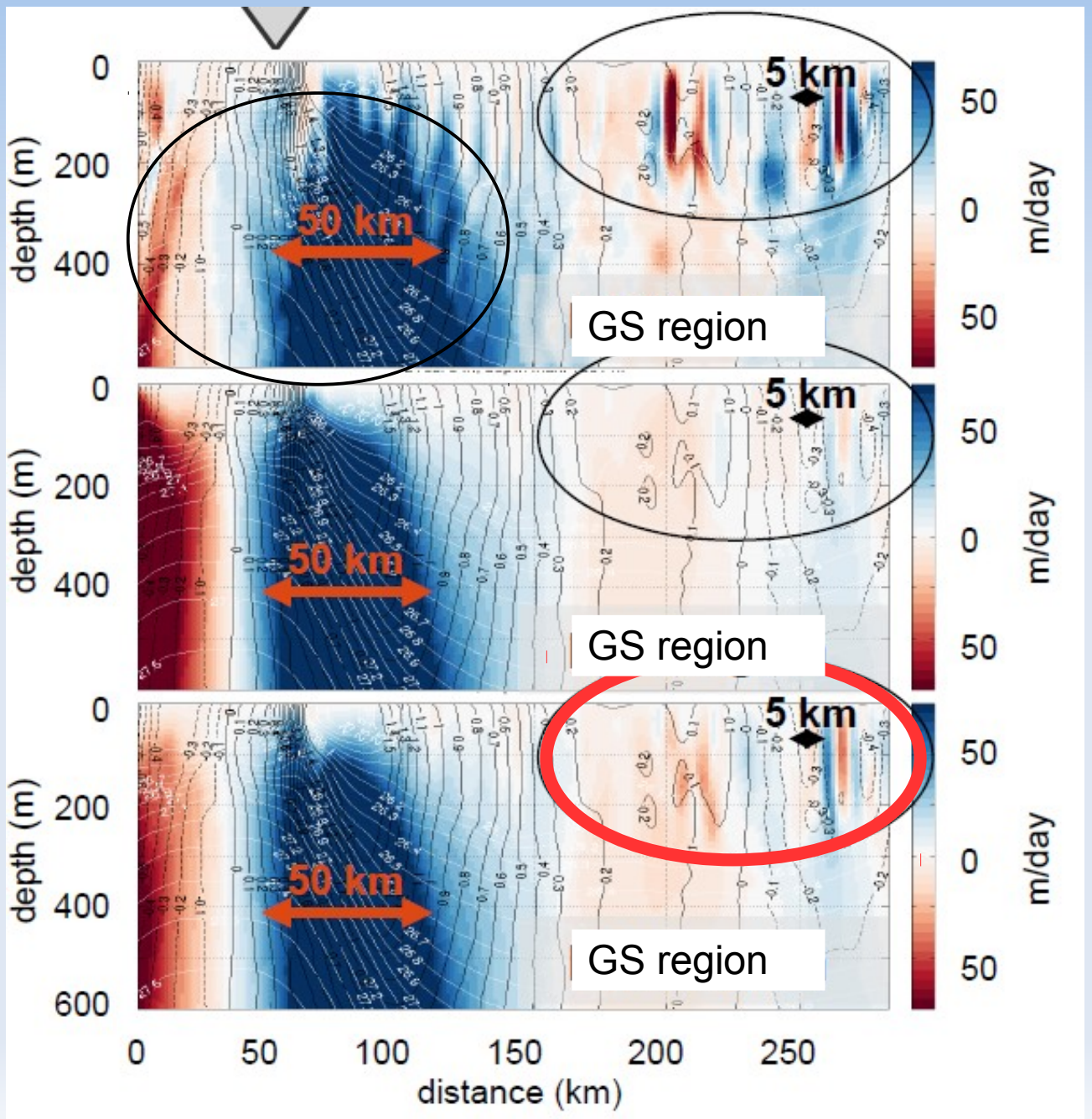


Vertical velocity reconstruction in GS region (Pietri, Capet and D'ovidio)

W from model

W from QG and non-geostrophic terms (e.g. surface fluxes)

Reconstruction of w at submesoscales (5km) and in the mixed layer



- Omega-equation using QG terms does a good job
  - In regions of very intense mesoscales
    (e.g. Gulf Stream, Kuroshio)
  - For scales larger than 60km and for deep motions
- Ageostrophic terms and surface fluxes improve the reconstruction
  - For scales larger than 30km and subsurface motions
  - In regions of weak mesoscales or strong surface fluxes
    (e.g. NorthEast Atlantic)
- Results depend on season and location (not shown)

- Next step: How does SWOT noise affect reconstruction?

2nd method: Vertical velocity from SQG theory

SQG= Assumption of no PV anomalies

$$PV = \nabla_H^2 \psi + \frac{\partial}{\partial z}\left(\frac{f_0^2}{N^2}\frac{\partial \psi}{\partial z}\right) = 0$$

with

$$\left.\frac{\partial \psi}{\partial z}\right|_{z=0} = -\frac{g}{f_0 \rho_0}\rho_s$$

Horizontal flow reconstruction:

$$\widehat{\psi}(\mathbf{k}, z) = \frac{g}{f_0}\,\widehat{\eta}\,\exp\left(\frac{N}{f_0}kz\right) = -\frac{g}{N\rho_0\,k}\,\widehat{\rho}_s\,\exp\left(\frac{N}{f_0}kz\right)$$

In horizontal Fourier space

with

$$\begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} -\partial_y \psi \\ \partial_x \psi \end{pmatrix}$$

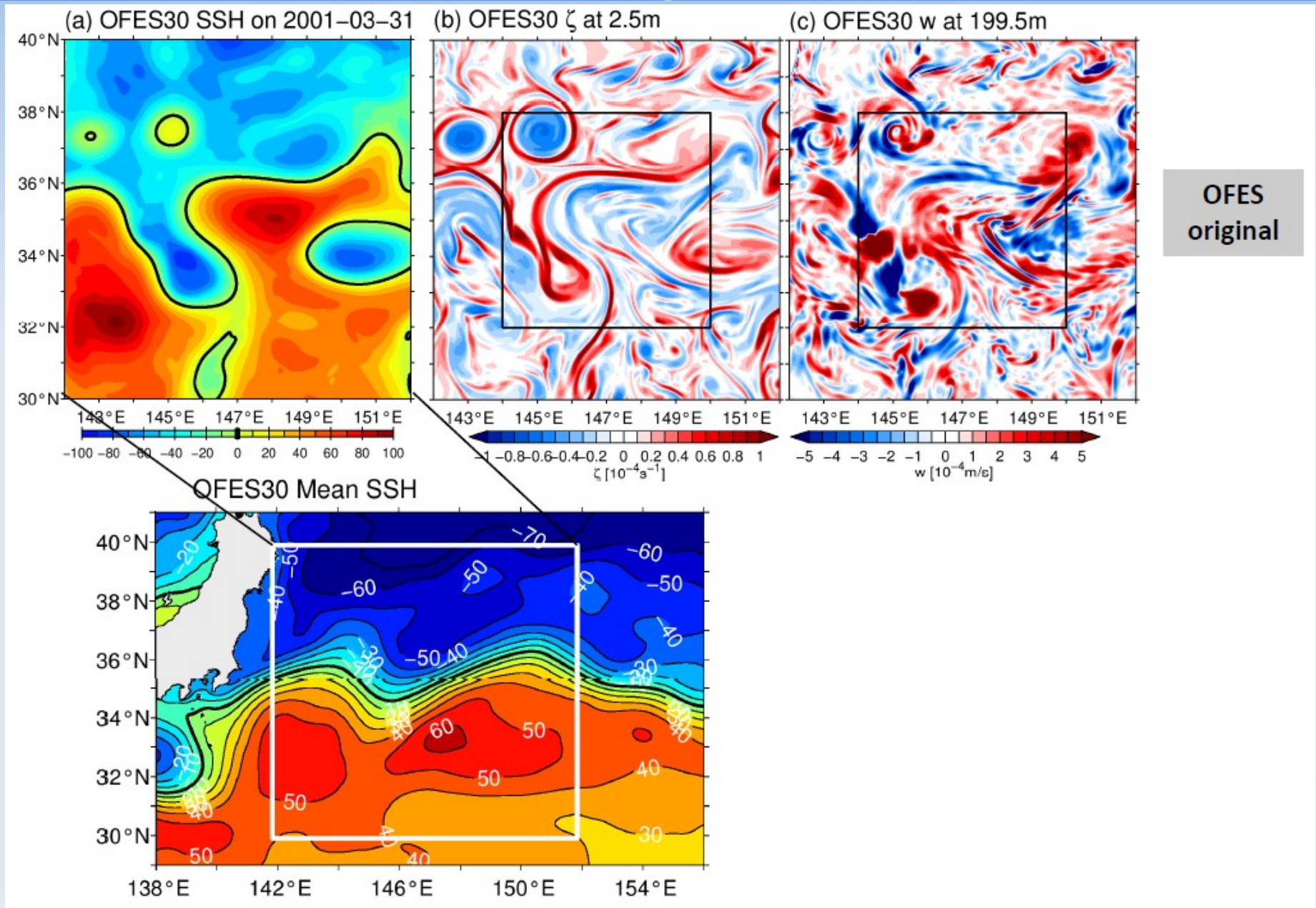
Vertical flow reconstruction:

$$\widehat{w} = \frac{1}{N^2}\left(-\widehat{J(\psi_s,\ b_s)}\exp\left(\frac{N}{f_0}|k|\,z\right) + \widehat{J(\psi,\ b)}\right)$$

with

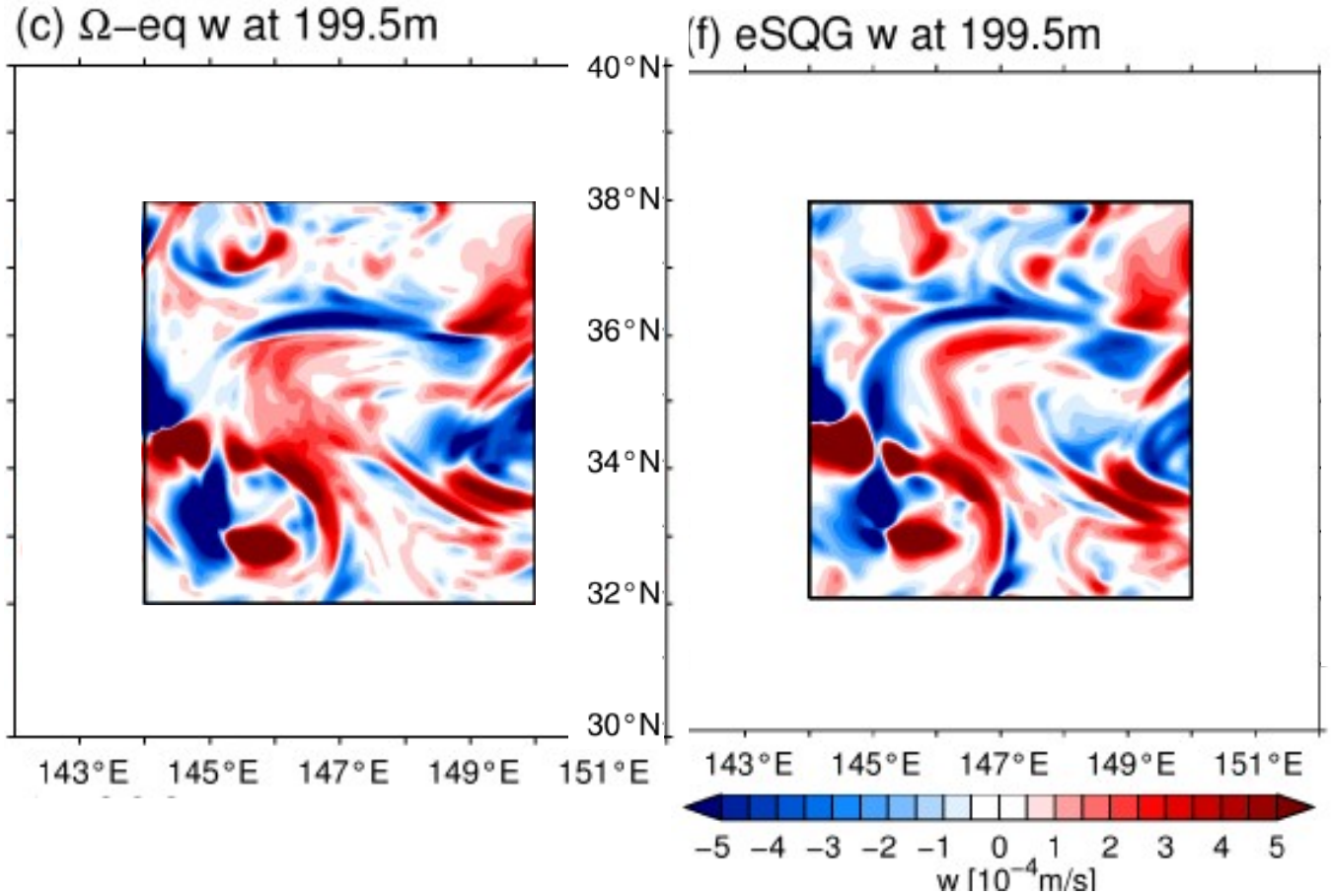
$$b = -\frac{g\rho}{\rho_0}$$

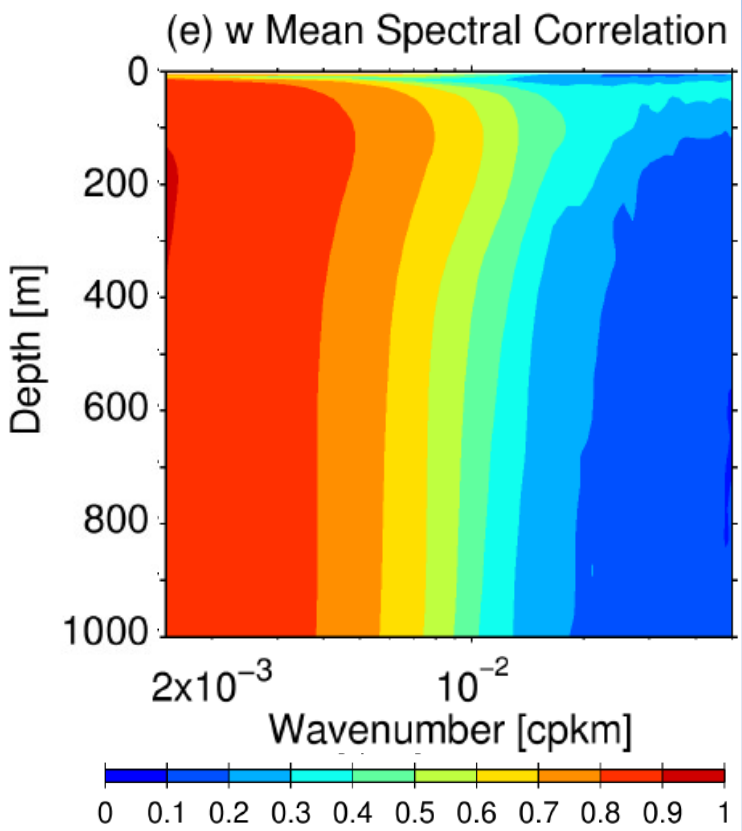
A specific example:
Kuroshio extension region (Qiu et al., 2016, JPO)



OFES original

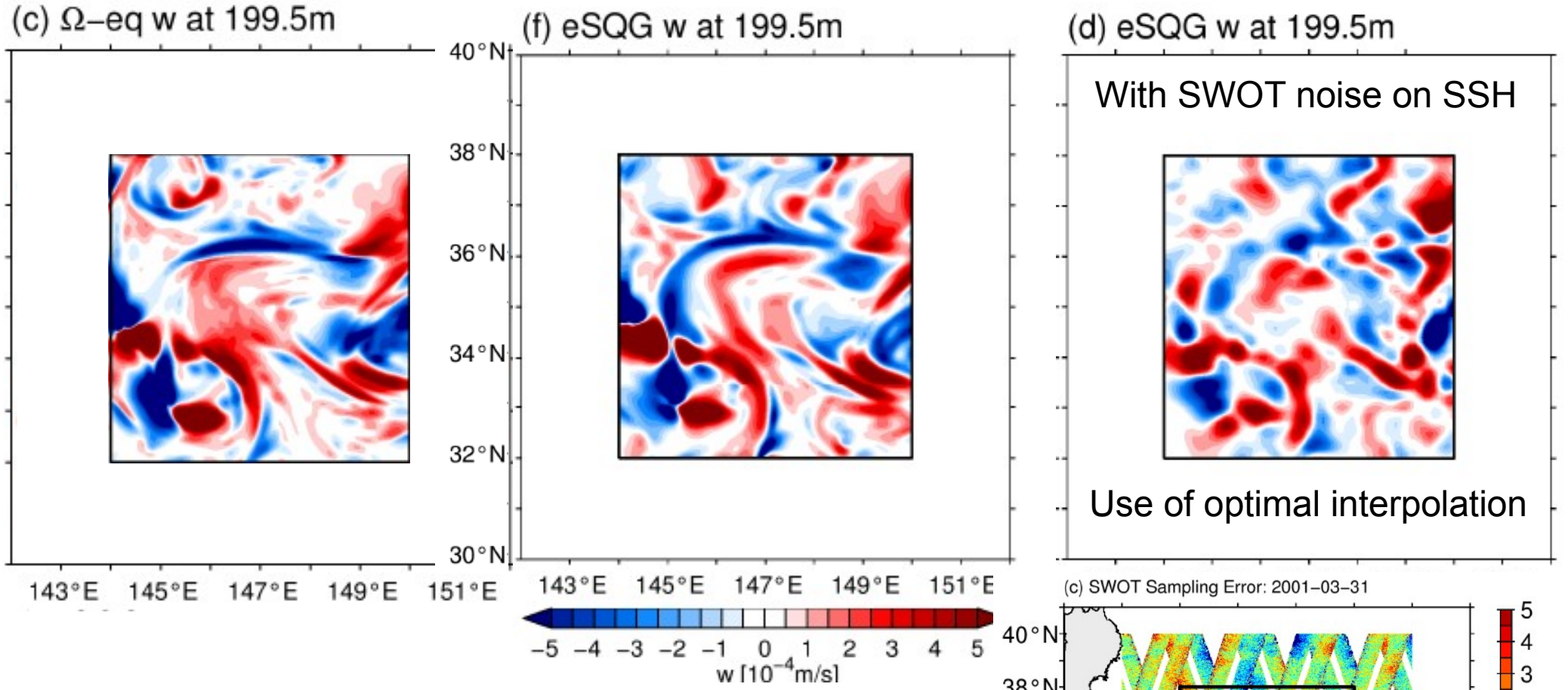
SQG reconstruction with modeled SSH and no SWOT errors

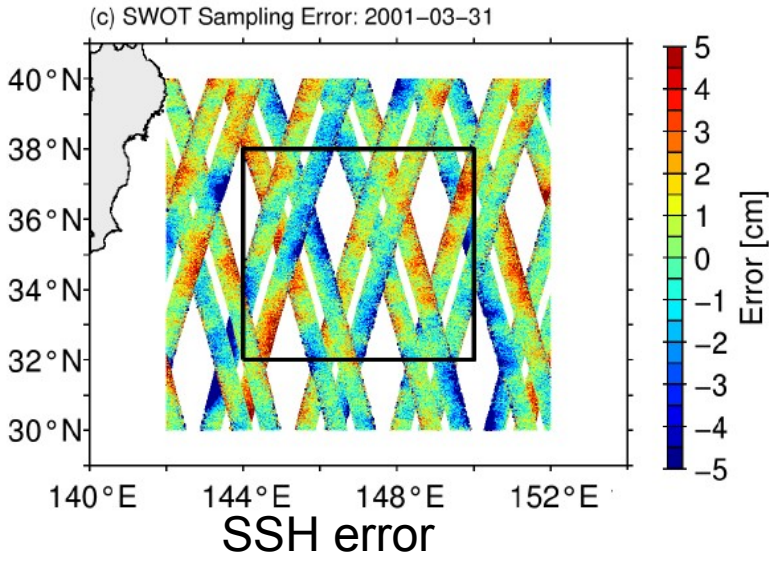




Good reconstructability of w at 200m
but fails in the MXL
and only for ”balanced” mesoscales

SQG reconstruction with modeled SSH and no SWOT errors





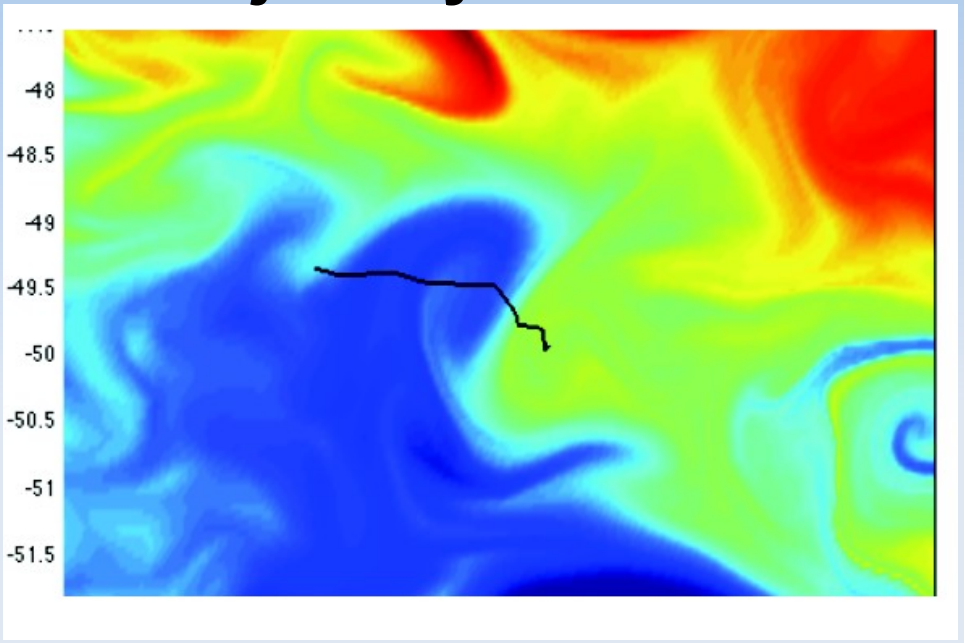
SSH error

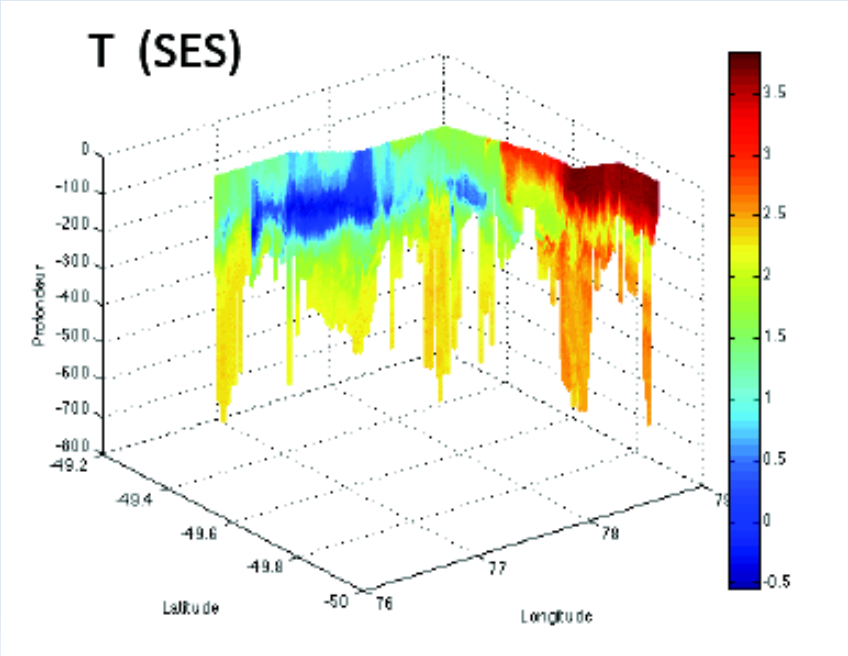
SQG method still works at mesoscale when SWOT noise is present

=> use optimal interpolation to smooth out small-scale signal

Retrieving ocean dynamics using elephant seals

Trajectory and SST

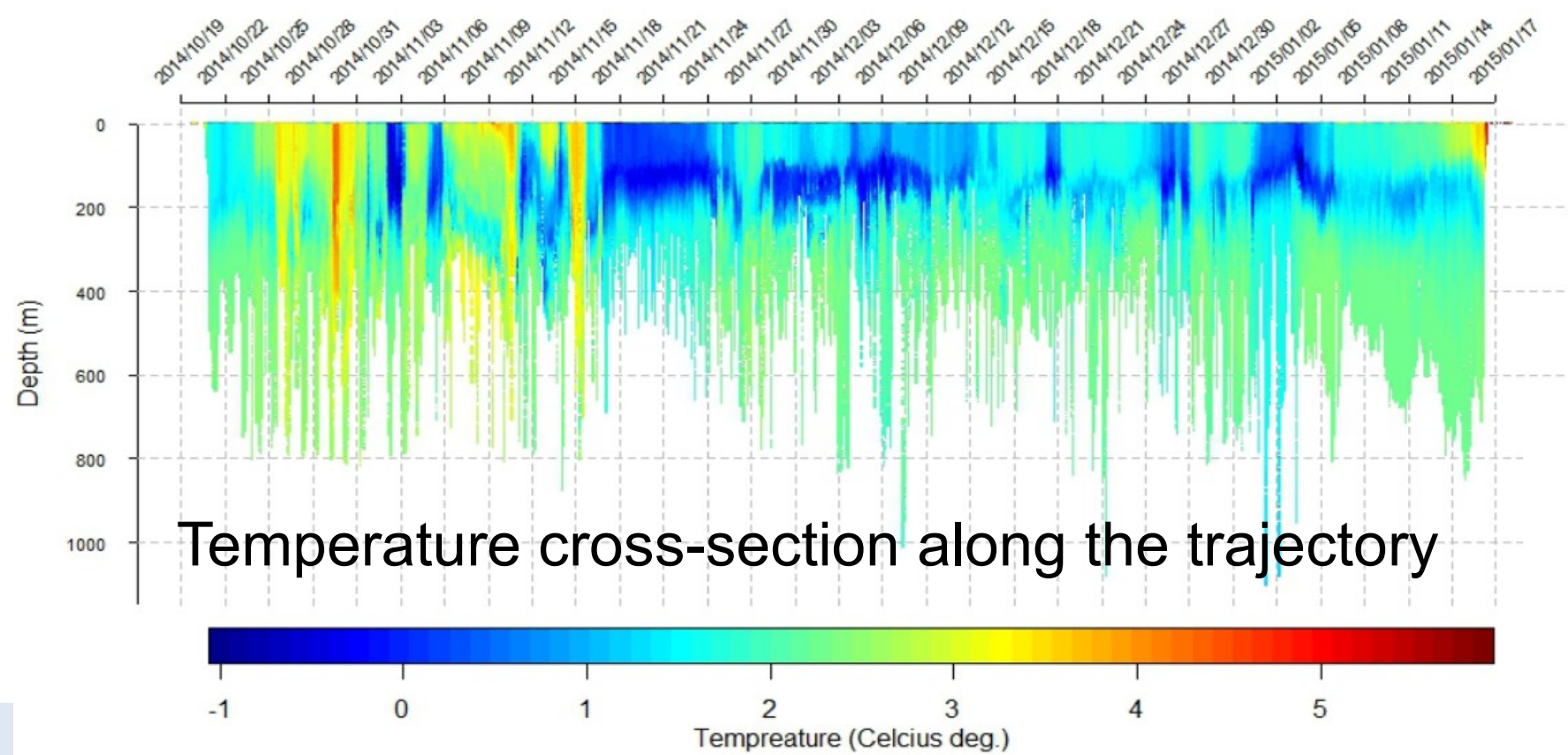


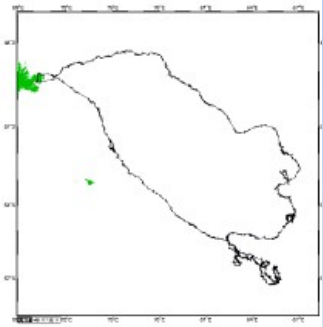


They swim from Kerguelen Island to the ACC and can be tracked by GPS

Provide high-resolution ”in situ” T/S with vertical resolution when they dive

Towards vertical velocity reconstruction
(P. Rivière, P. Klein, A. Ponte)





Two approaches will be compared:

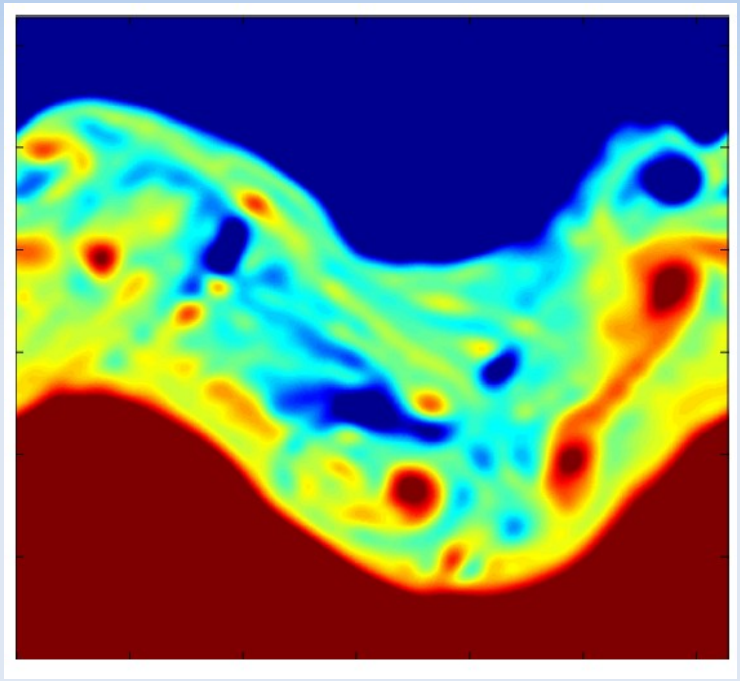
- Compute vertical velocities
  - from omega-equation
  - using vertical cross-section of density field (Legal et al. 2007)

- From sQG method with SSH signal

Thanks
for your attention

Coupling tracer reconstruction and SQG reconstruction (Berti and Lapeyre)

Typical (microwave) SST from satellite



Smoothed field
but with daily resolution

Taken from a simulation of
idealized turbulence

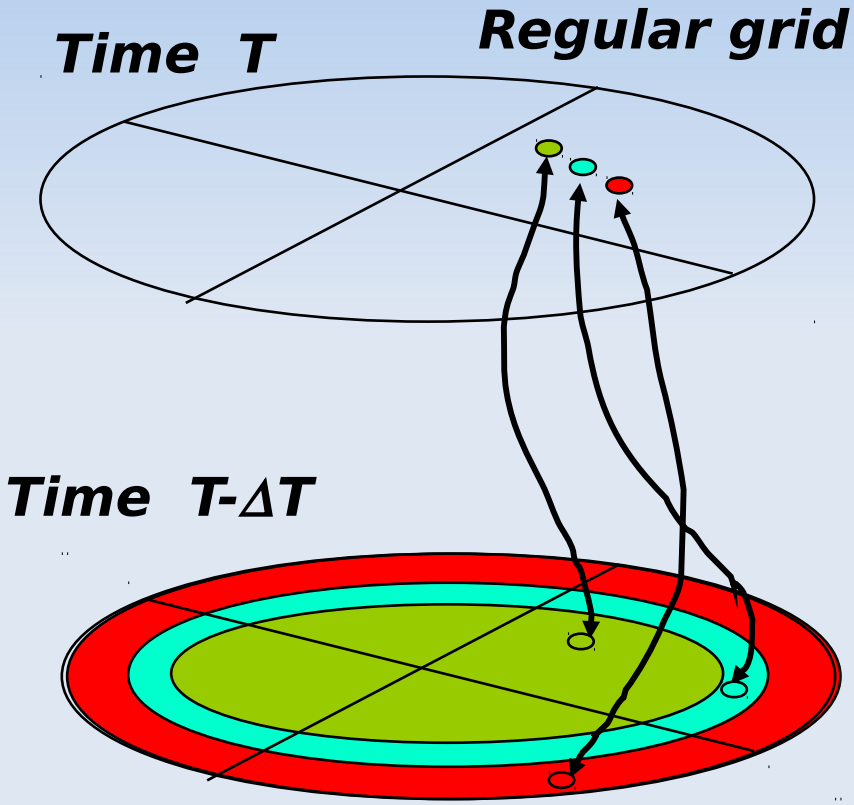
How to reconstruct submesoscales from smoothed data?

Can we reconstruct both SST and currents?

Tracer reconstruction at submesoscale

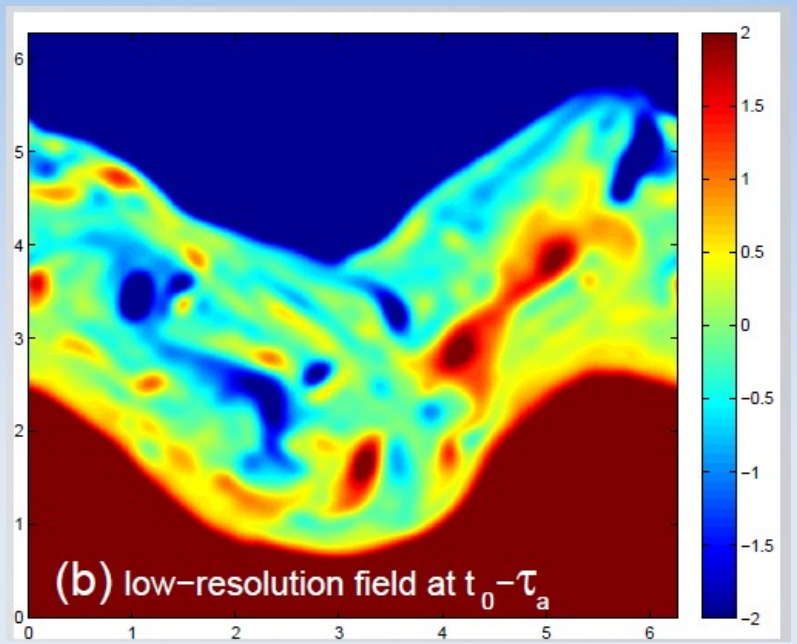
- ***Step 1***
  Run a back trajectories starting with a regular gridded array

- ***Step 2***
  Copy values forward to regular grid



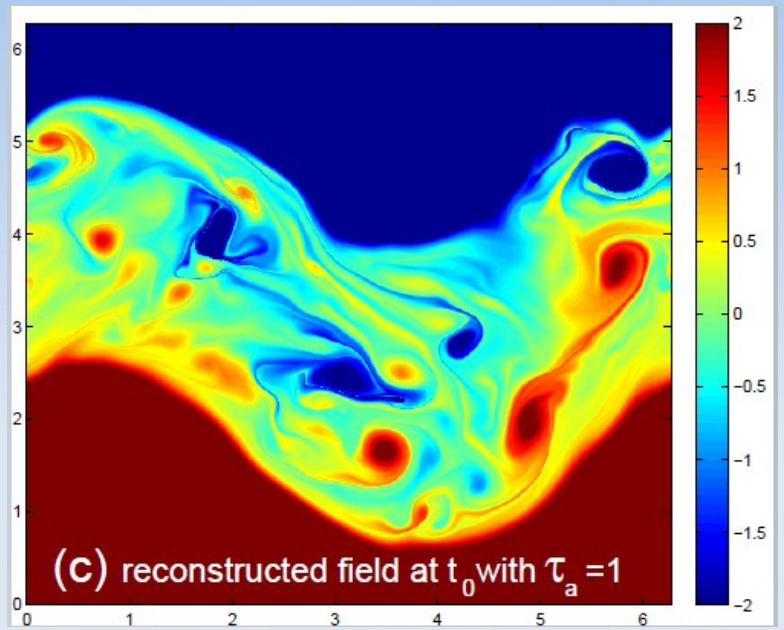
Similar to computation of (FSLE) Lyapunov Exponents
Small scales generated by advection by mesoscale eddies

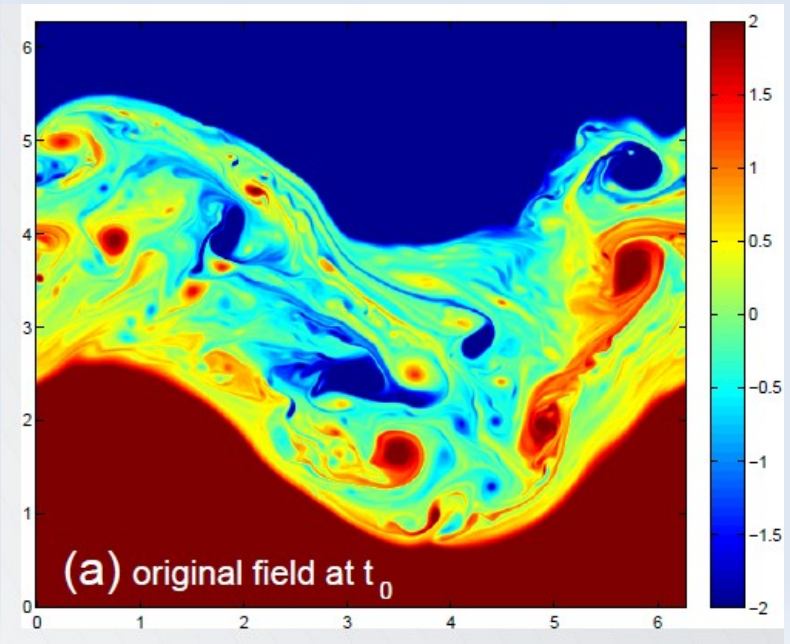
Tracer reconstruction



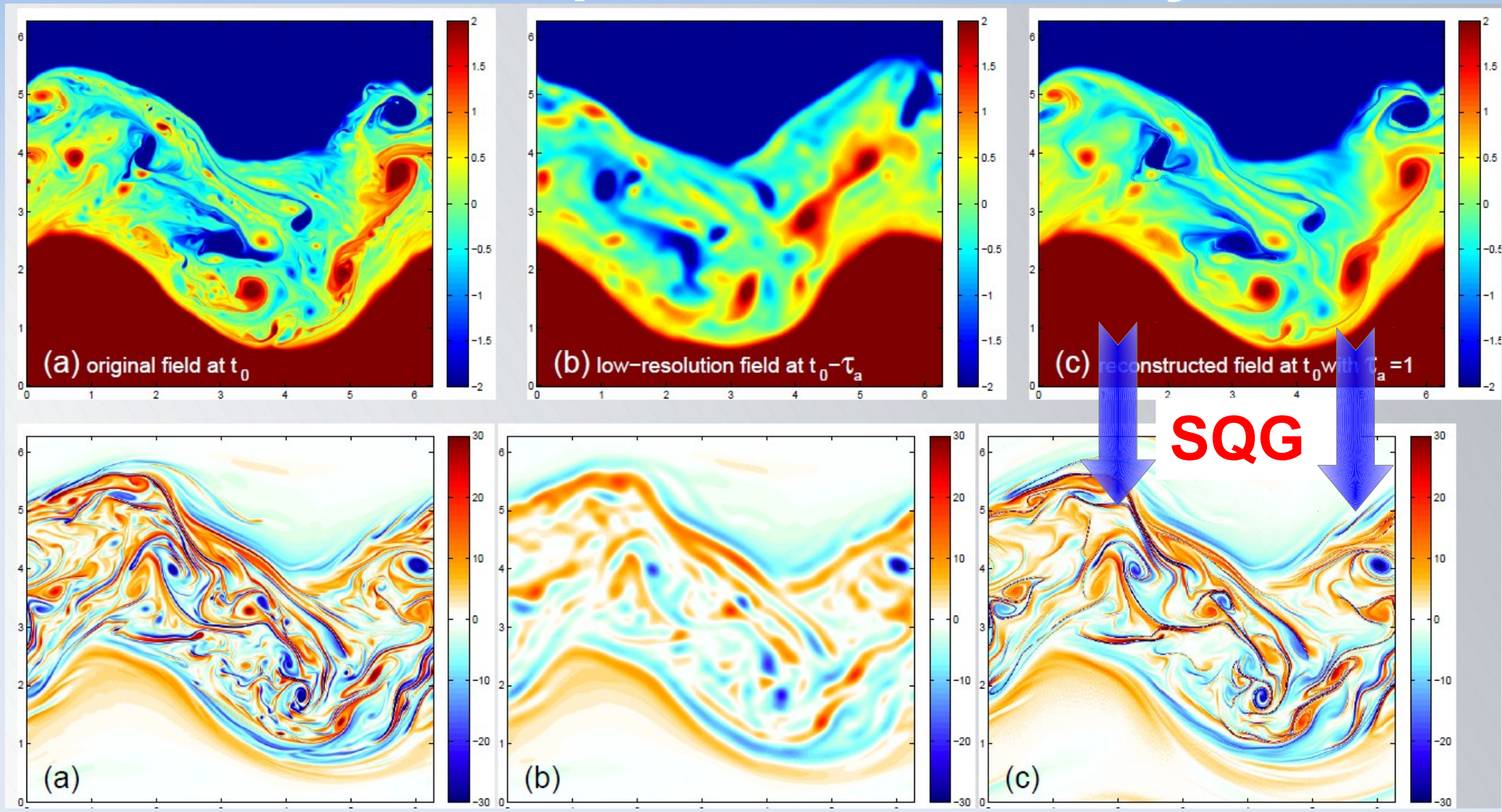
Backward advection

Tracer reconstruction





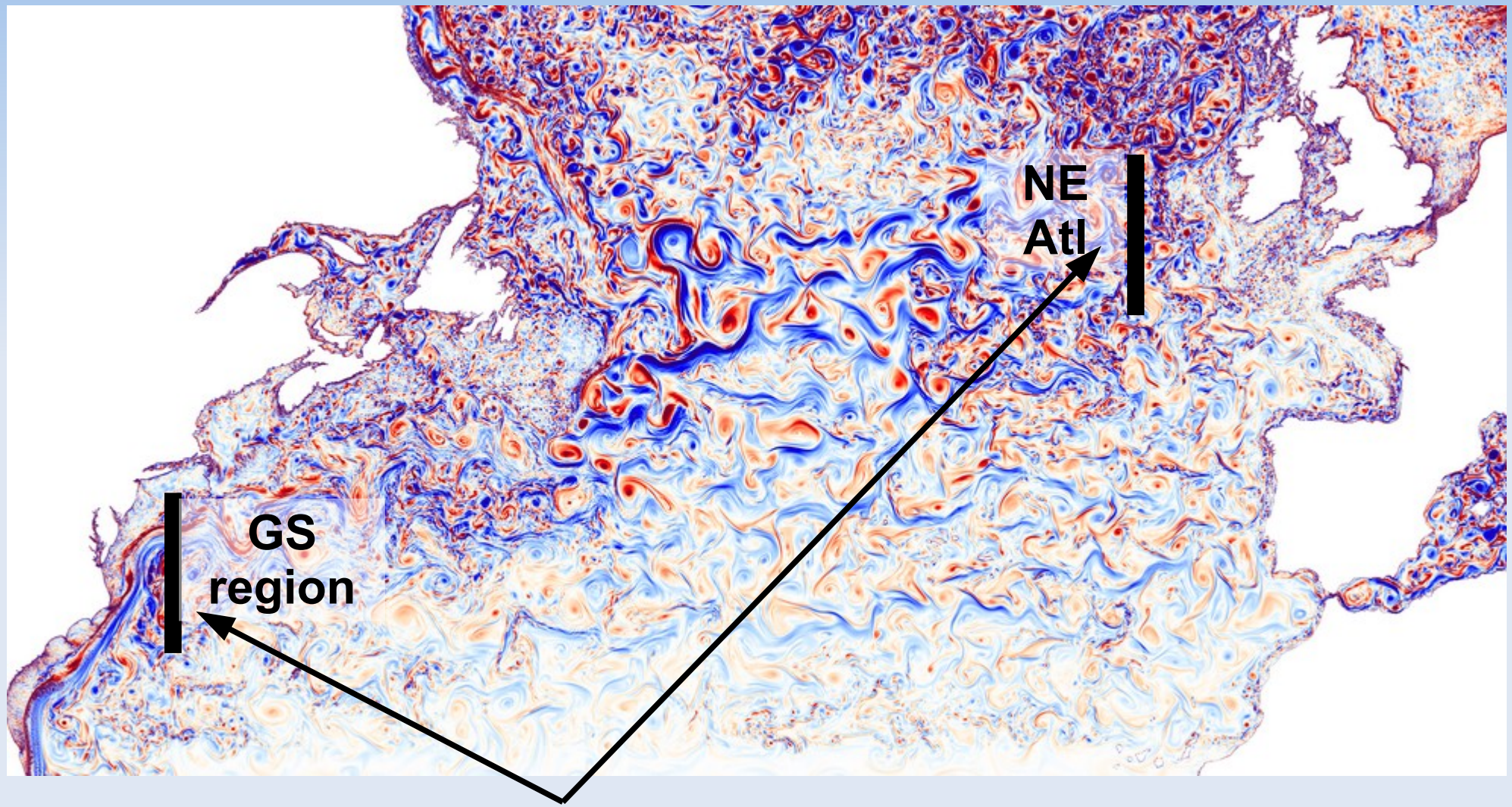
SQG reconstruction: from temperature to velocity



Relative vorticity

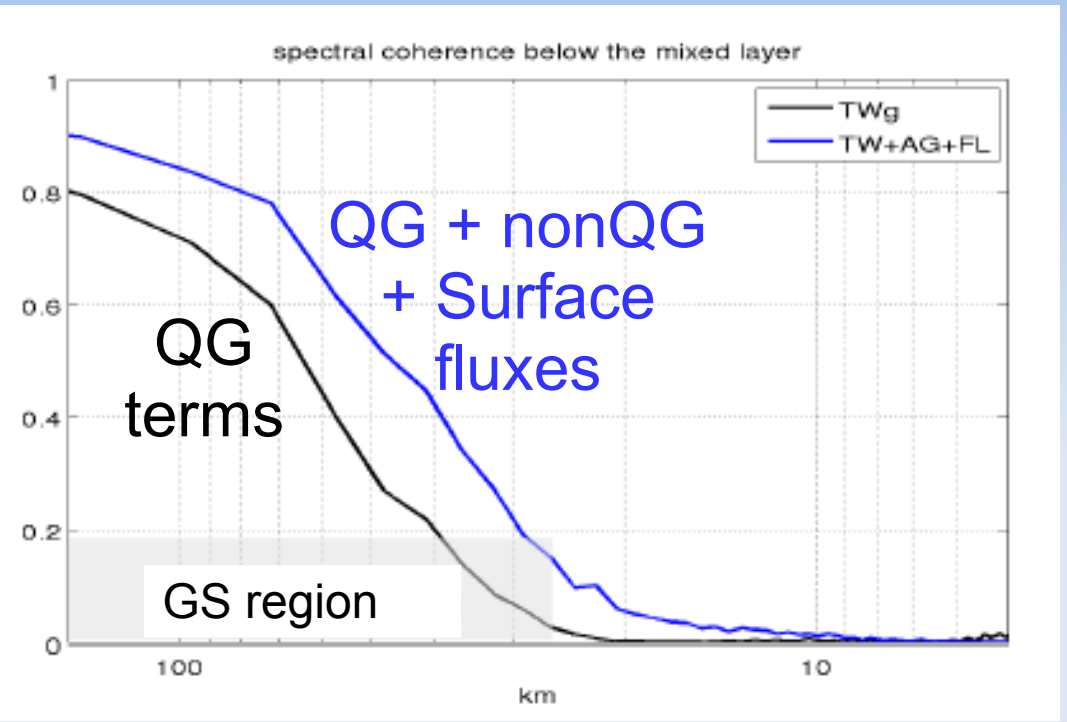
$$\hat{\zeta} = k\,\widehat{SST}$$

North Atlantic simulation (1/60deg) (LGGE team, Grenoble)

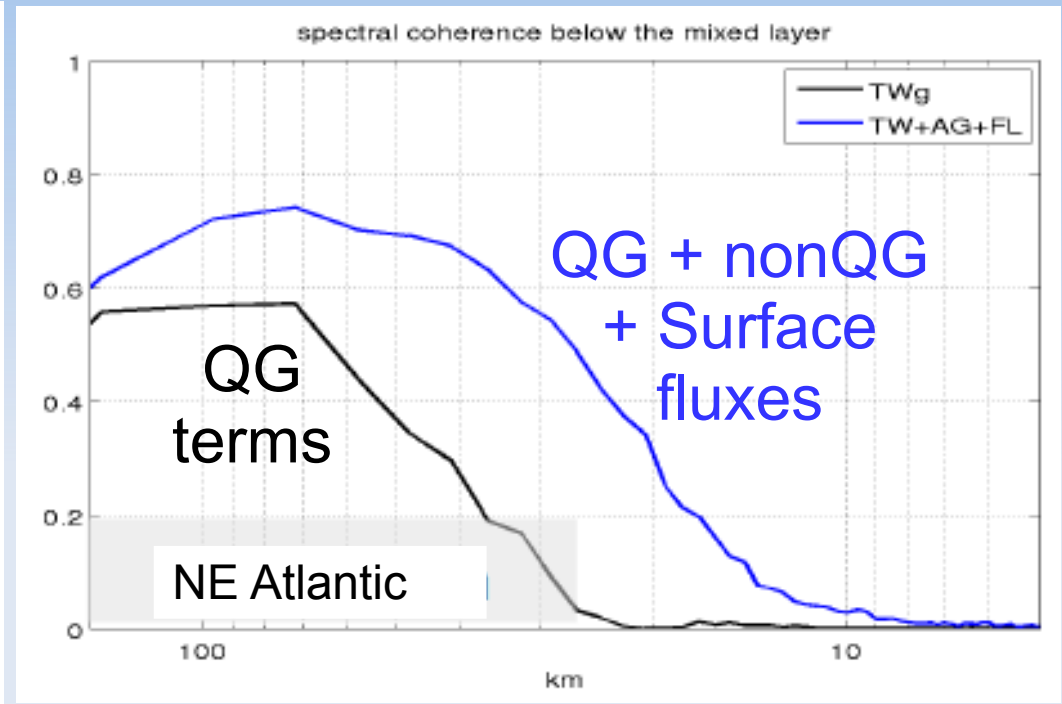


Vertical cross sections in order to look at vertical velocities reconstruction

Validity of reconstruction of w at 300m depth as a function of lengthcale



GS: omega-equation from QG terms does a fair job



NE Atl: nongeostrophic terms are crucial for a good reconstruction

Good reconstructions with

- QG terms only — only for mesoscales > 60km
- adding nongeostrophic terms — up to 30km

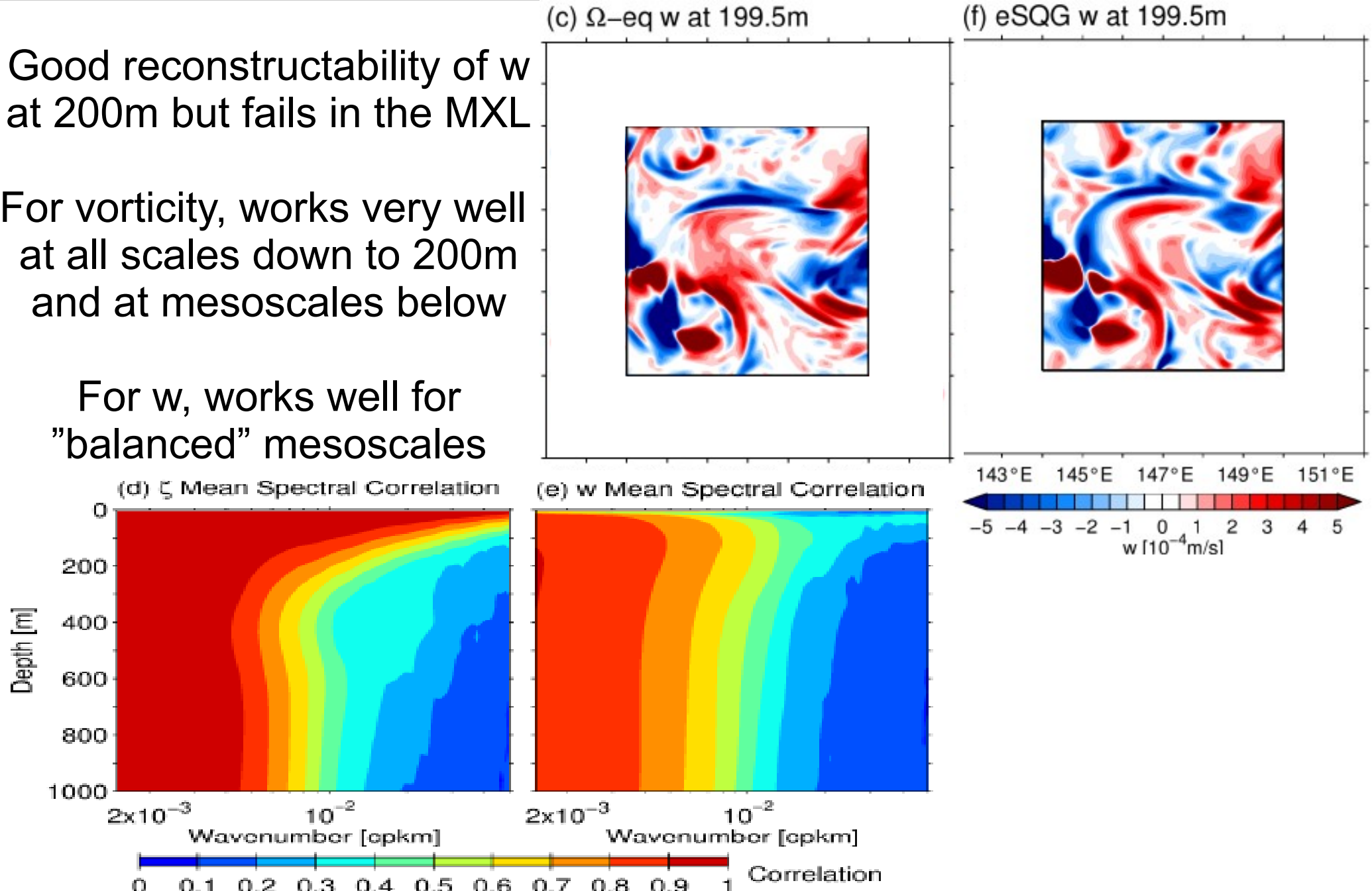
Depends on region of study and season

SQG reconstruction with modeled SSH and no SWOT errors

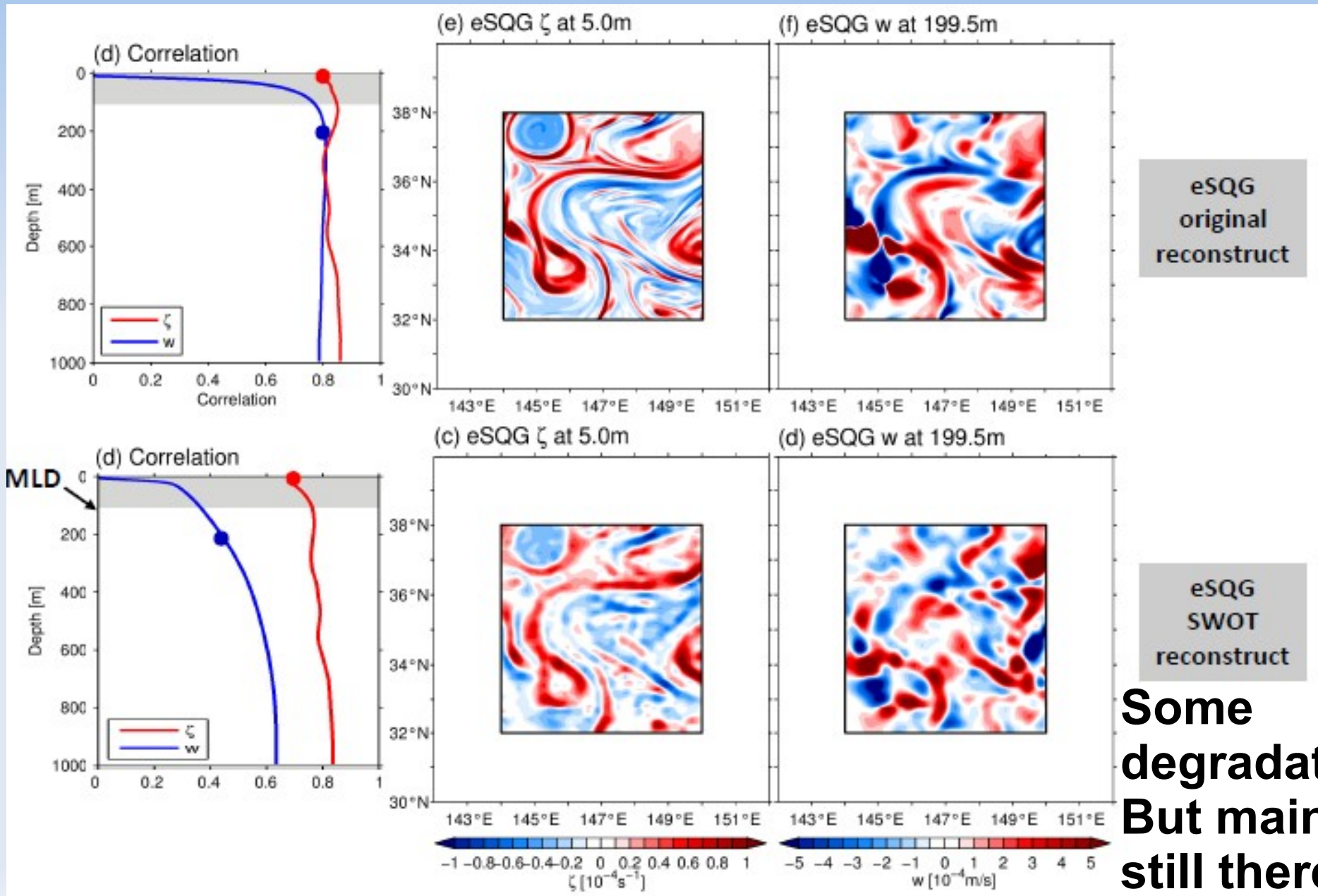
Good reconstructability of w at 200m but fails in the MXL

For vorticity, works very well at all scales down to 200m and at mesoscales below

For w, works well for ”balanced” mesoscales

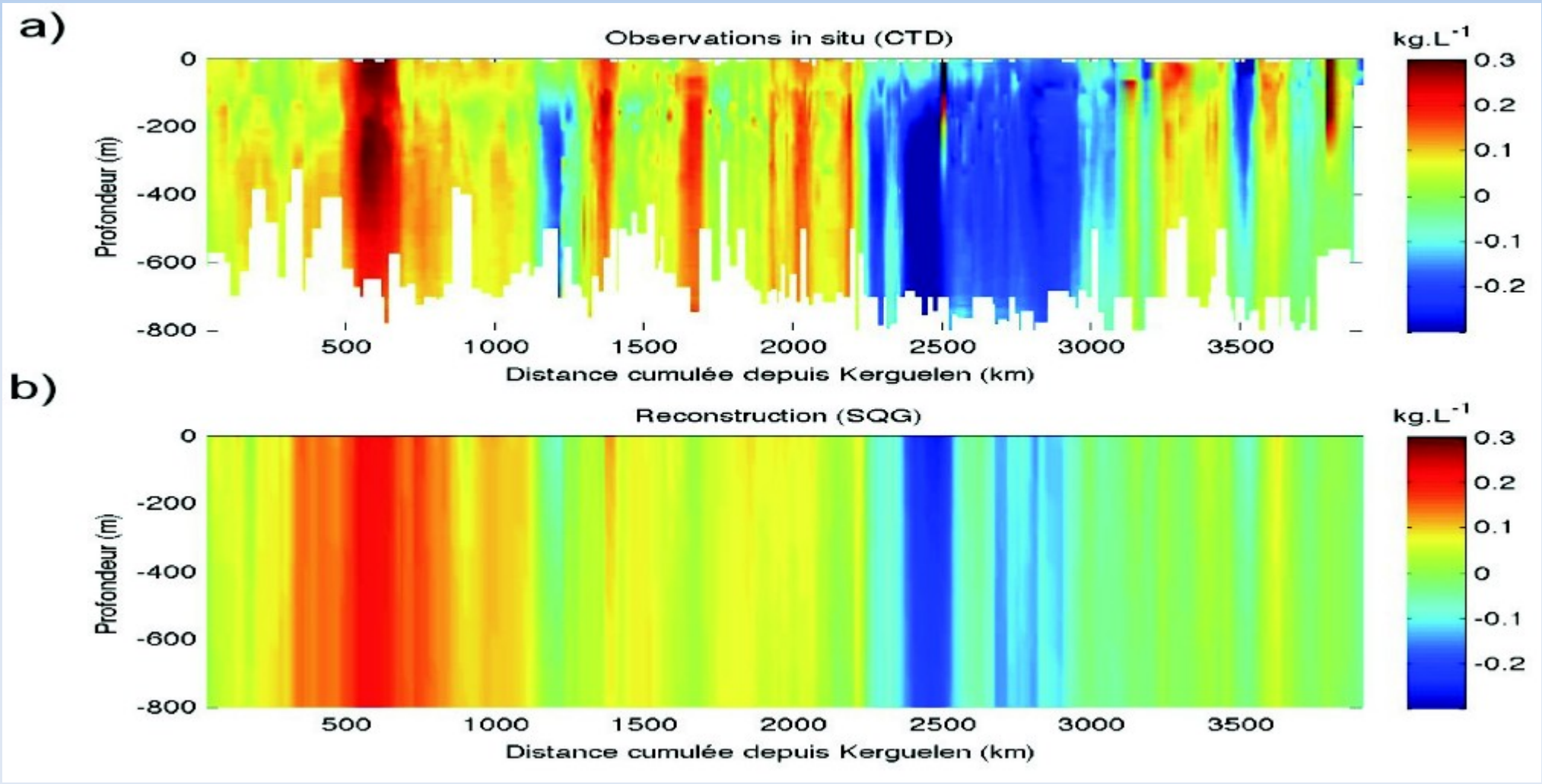


Comparison: SQG reconstruction using noise-free or SWOT simulator SSHs



Some degradation But main signal still there

Observed density from ”in situ” data



SQG reconstruction using satellite SST